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# Fluidization of mixed $\text{SiO}_2$ and $\text{TiO}_2$ nanoparticles with FCC coarse particles

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## Abstract

Fluidization behavior of the mixture of  $\text{SiO}_2$  and  $\text{TiO}_2$  nanoparticles by adding FCC coarse particles was investigated. The results showed that the fluidization quality of the mixture system can be obviously improved with adding FCC coarse particles. The size and mass percentage of FCC coarse particles are very important to the fluidization behavior of nanoparticle mixtures. For the mixture system of  $\text{SiO}_2$  and  $\text{TiO}_2$  nanoparticles, the minimum fluidization velocity decreases obviously for the optimum adding FCC size (61 to 90  $\mu\text{m}$ ) and the FCC adding percentage of 30%. The observation showed that the majority of the agglomerates were looser and smaller for the samples obtained in the upper of the bed. Adding the FCC coarse particles to the mixture of the content of  $\text{SiO}_2$  nanoparticles of 30%, 50% and 70%, the minimum fluidization velocity of the mixture system was dropped to 0.062, 0.058, 0.053 m/s, respectively.

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**Keywords:** *Nanoparticles; Fluidization; Mixture; adding; FCC*

## 1. Introduction

Nanoparticles are very attractive for various industrial applications due to their chemical, optical, biological and electrical characteristics. Therefore, it is necessary to develop processing technologies that can handle large

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**Nomenclature**

$H$	bed height, m
$h_0$	initial bed height, m
$\Delta p$	pressure drop, Pa
$U_g$	the superficial gas velocity, m/s
$U_t$	the terminal gas velocity, m/s

quantities of nanoparticles, such as mixing, transporting, modifying the surface properties (coating). One important means for nanoparticle processing is fluidization.

The fluidization characteristics of nanoparticles were investigated by many scholars [1–6] from various aspects. Nevertheless, on the basis of their primary particle size and material density, nano-sized powders fall into the Geldart C ( $<30 \mu\text{m}$ ) classification, which means that fluidization is expected to be particularly difficult (i.e. characterized by plug formation, channeling and agglomeration) because of cohesive forces (such as van der Waals, electrostatic and moisture induced surface tension forces) existing between particles and becoming more and more prominent as the particle size decreases. However, there are growing experimental evidences that nanoparticles can be smoothly fluidized for an extended window of gas velocities, thus implying that primary particle size and density cannot be taken as representative parameters for predicting their fluidization behavior. In fact, because of the interparticle forces mentioned above, nanoparticles are always found to be in the form of large-sized porous aggregates [7, 8], rather than as individual nanosized particles, when packed together in a gaseous medium. Therefore, gas fluidization of nanoparticles actually occurs in the form of nanoparticle aggregates, and their properties (size/density) highly affect the fluidization feature.

According to different experimental campaigns [1], highly porous nanoparticle aggregates can exhibit two distinct fluidization behaviors: APF (agglomerate particulate fluidization) and ABF (agglomerate bubbling fluidization). The former is characterized by very large bed expansion, smooth fluidization and very low minimum fluidization velocity; while the latter, instead, shows little bed expansion and bubbling.

Many methods were developed to improve the fluidization behavior of nanoparticles, for example, adding coarse particles to the bed [9–11] and introducing a magnetic field [12–14], acoustic field [15,16], or vibrating field [17–19]. Contrasted with other methods, the advantage of adding coarse particles is that it is unnecessary to get additional equipment or devices.

The method of mixing with coarse particles is to add some coarse particles into the nanoparticle beds, working as agglomerate breakers to reduce the interparticle forces among nanoparticles. There are some literatures about fluidization behavior of single nanoparticles by adding coarse particles [20], but few studies can be found in literature in different mixed nanoparticles. Present work is focused on the fluidization behavior of binary mixed nanoparticles by adding FCC coarse particles.

## 2. Experimental

The cylinder of the fluidization bed (40 mm ID and 700 mm high) is made of Plexiglas to minimize the static electricity, and a porous plate gas distributor is installed in the bottom. Compressed air which is regarded as fluidization medium is dried while through a fixed bed of silica gel to minimize the effect of humidity on fluidization of nanoparticles. The flow rate, called superficial gas velocity,  $u_g$ , is controlled between 0 and 0.133 m/s by a rotameter. Pressure drop across the whole particle bed is measured by a tilted U-tube manometer. Because of the intensive data point, the minimum fluidization velocity could use velocity of the start point which the pressure drop is stable. The bed expansion ratio is calculated by bed height which is measured by a ruler tape placed at the cylinder wall. Samples measured by microscope are taken out in the upper part of the bed. The data is recorded after seconds and the phenomenon of the bed is reproducible. All of the tests were carried out at room temperature and ambient pressure conditions.

Nanoparticles used in the tests are  $\text{SiO}_2$  and  $\text{TiO}_2$  nanoparticles and some of their physical properties are listed in Table 1. Coarse particles used are fluid catalytic cracking (FCC) particles. The FCC particles are meshed to the

diameter from 61-90  $\mu\text{m}$  before experiments. The single or binary mixed nanoparticles of different content loaded to the bed are a fixed height of about 80 mm ( $h_0/D=2$ ) (nanoparticles are dried about 2 hours before the experiments). The ratio of  $\text{SiO}_2$  or  $\text{TiO}_2$  nanoparticles is the mass ratio and the ratio of added coarse particles is the mass of FCC over mass of mixed nanoparticles. The pressure drop  $\Delta p$  and bed expansion ratio ( $h/h_0$ ) curves of different content binary mixtures of nanoparticles with and without coarse particles are used to characterize the fluidization performance of nanoparticles.

Table 1 Properties of nanoparticles.

Power	Color	Shape	Size(nm)	Bulk density( $\text{kg/m}^3$ )	Primary density( $\text{kg/m}^3$ )
$\text{SiO}_2$	White	Spheriform	30	108	2560
$\text{TiO}_2$	White	Claviform	10	263	3850

### 3. Results and discussion

#### 3.1. Fluidization behavior of mixed nanoparticles.

As it well known, due to strong interparticle forces, electrostatic forces and liquid bridging forces, nano-particles tend to agglomerate each other and form channels or plug in conventional fluidized beds at lower gas velocities, which often lead to poor fluidization or defluidization. In the experiments, mixed  $\text{SiO}_2$  and  $\text{TiO}_2$  nanoparticles were fluidized in the traditional fluidized bed. The result shows that a fixed bed of nanoparticles formed at low superficial gas velocities, and crack formed in the process. With the increase of the gas velocity to certain values, nanoparticle agglomerate beds become fluidizing at the upper part of the bed. However, nanoparticles still cannot be fluidized perfectly at high gas velocity.

Typical fluidization curves, that is, pressure drop ( $\Delta p$ ) and bed expansion ratio ( $h/h_0$ ) curves, for  $\text{TiO}_2$  and  $\text{SiO}_2$  nanoparticles are shown in Fig. 1. The results show that the minimum fluidization velocity is greater while the mass percentage of  $\text{SiO}_2$  nanoparticles is greater. The minimum fluidization velocities are 0.0106, 0.0106 and 0.088 m/s in bed when the mass percentage of  $\text{SiO}_2$  nanoparticles is 30%, 50% and 70%, respectively. The bed expansion ratio increases with increasing the mass percentage of  $\text{SiO}_2$  nanoparticles.

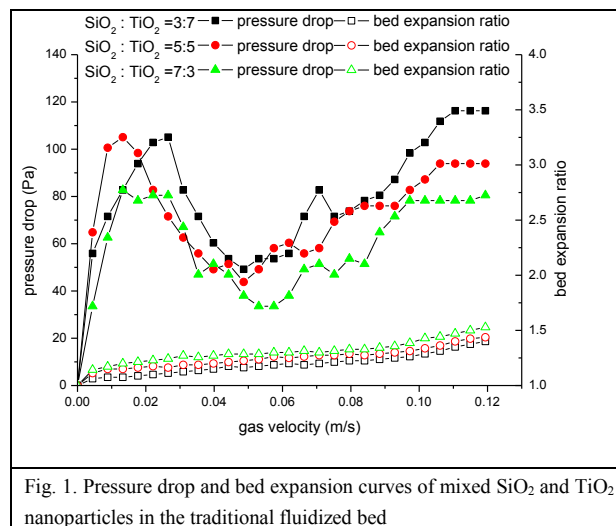


Fig. 1. Pressure drop and bed expansion curves of mixed  $\text{SiO}_2$  and  $\text{TiO}_2$  nanoparticles in the traditional fluidized bed

### 3.2. Fluidization behavior of mixed nanoparticles with FCC particles.

According to the present work, the minimum fluidization velocities of  $\text{SiO}_2$  nanoparticles by adding FCC particles decrease to 0.0398, 0.0265, 0.0177 m/s responding to the adding amount of FCC of 15%, 30% and 45%, respectively. And the minimum fluidization velocities of  $\text{TiO}_2$  nanoparticles by adding FCC particles decrease to 0.0928, 0.084, 0.0752 m/s responding to the adding amount of FCC of 15%, 30% and 45%, respectively. Obviously, the fluidization behavior of single nanoparticles by adding FCC particles is improved.

Figs. 2-4 show pressure drop and bed expansion curves of different amount of  $\text{SiO}_2$  and  $\text{TiO}_2$  nanoparticles and adding FCC coarse particles. It can be seen that there are differences among same binary mixed nanoparticles with different size of FCC coarse particles. All of these three kinds of FCC particles can improve the fluidization behavior of mixed nanoparticles. The minimum fluidization velocities decrease and beds expansion ratio increases with increasing the mess ratio of FCC to mixed nanoparticles. In the mixed bed of 70%  $\text{SiO}_2$  and 30%  $\text{TiO}_2$  nanoparticles, the minimum fluidization velocity decreases to 0.0663, 0.0531, and 0.0354 m/s responding to the adding amount of FCC of 15%, 30% and 45%, respectively. For the mixed bed of 50%  $\text{SiO}_2$  and 50%  $\text{TiO}_2$  nanoparticles, the minimum fluidization velocity decreases to 0.007, 0.0575 and 0.0398 m/s for the adding amount of FCC of 15%, 30% and 45%, respectively. The minimum fluidization velocity reduces to 0.0796, 0.0619 and 0.0442 m/s for the adding amount of FCC of 15%, 30% and 45%, in mixed bed of 30%  $\text{SiO}_2$  and 70%  $\text{TiO}_2$  nanoparticles, respectively. It can be concluded that adding FCC coarse particles can improve the fluidization behavior of mixed nanoparticles. This improvement is made by two ways. Entering the agglomerates and transforming the structure require a large and coarse surface, which needs a small size of FCC particles. Crashing and friction require a higher kinetic energy, which needs larger FCC particles. In the bed of majority  $\text{SiO}_2$  nanoparticles, adding FCC coarse particles is better because of the low density of  $\text{SiO}_2$  nanoparticles. But for the bed of majority  $\text{TiO}_2$  nanoparticles, it requires more kinetic energy since the density of  $\text{TiO}_2$  nanoparticles is more than 3 times of density of  $\text{SiO}_2$  nanoparticles. Therefore, adding larger FCC coarse particles to the bed of  $\text{TiO}_2$  nanoparticles is more effective. It can also be seen that the fluidization behavior is improved obviously if mess ratio of FCC particles increased from 15% to 30%. But if mess ratio of FCC particles increases from 30% to 45%, the fluidization behavior is only improved slightly. The SEM graph of samples of agglomerates is shown in Fig. 5. It can be seen that the FCC particles have entered into agglomerates. This is regarded as a possible way for FCC particles to improve the fluidization of mixed nanoparticles.

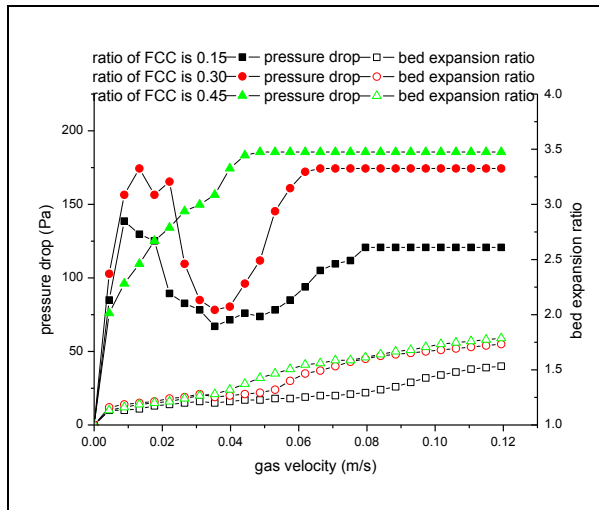


Fig.2. Pressure drop and bed expansion curves of 70%  $\text{SiO}_2$  and 30%  $\text{TiO}_2$  nanoparticles by adding FCC coarse particles

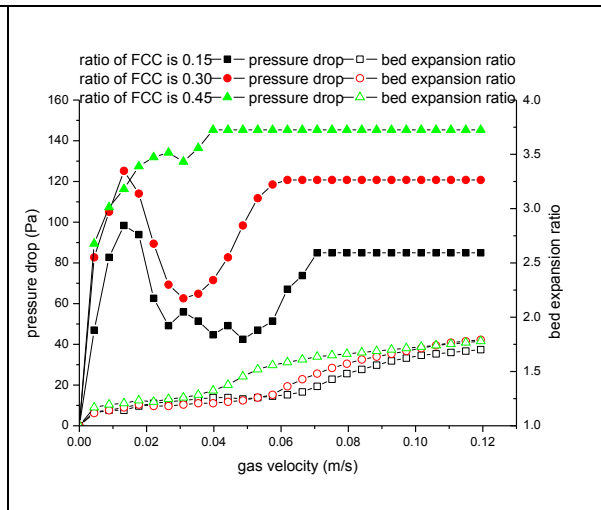


Fig.3. Pressure drop and bed expansion curves of 50%  $\text{SiO}_2$  and 50%  $\text{TiO}_2$  nanoparticles by adding FCC coarse particles

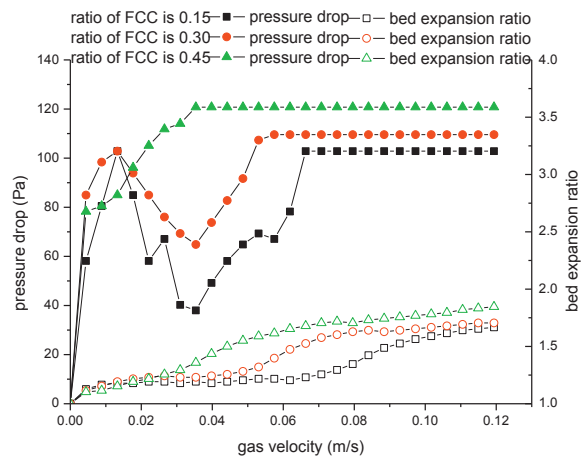


Fig.4. Pressure drop and bed expansion curves of 30% SiO<sub>2</sub> and 70% TiO<sub>2</sub> nanoparticles by adding FCC coarse particles

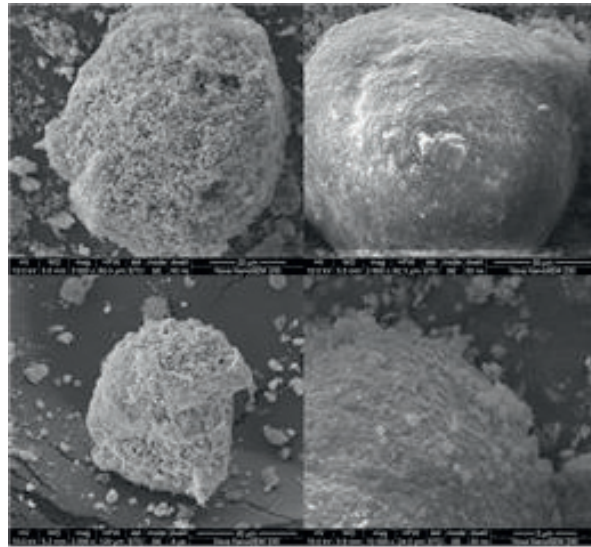


Fig. 5. SEM graph of agglomerates

#### 4. Conclusion.

The fluidization experiments of mixed SiO<sub>2</sub> and TiO<sub>2</sub> nanoparticles by adding FCC coarse particles were studied. The fluidization behavior of mixed nanoparticles can be improved further with increasing the adding amount of FCC coarse particles. The fluidization behavior of mixed SiO<sub>2</sub> and TiO<sub>2</sub> nanoparticles is improved obviously if mess ratio of FCC particles increased from 15% to 30%. The minimum fluidization velocities can largely decrease when the adding percentage of FCC coarse particles is 30% and 45%.

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